OXYGEN SUPPLY SYSTEMS FOR MILITARY FLYING*

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IN preparation for writing this paper, I took occasion to refer to an article which I read nearly nine months ago. As a matter of fact, it has not yet been published. In it I presumed to define in some detail the requirements of military oxygen supply apparatus in conformity with the necessity of meeting the requirements of the airplane, the service and the personnel.

The principles expressed at that time are as sound today as they were then but in re-reading it a few days ago, I was astonished at the progress which has been made since then. There was no intent then to create the inference of prophesy but, in retrospect, development of oxygen equipment and description of desiderata for such equipment have followed very closely the principles which were generally accepted then. Nor were the general principles then expressed considered as the implantation of seeds for the fruition which is presently to be garnered. Nevertheless, it is timely to describe equipment as it exists or is being developed today and to reiterate requirements in much more exact terms than was possible that short time ago.

The credit for the advances made cannot be given to any single individual or group of individuals. Contributors include service personnel, private research groups, federal agencies and the industry itself. No small measure of credit is due the National Research Council's Committee on Aviation Medicine. A far-sighted, comprehensive plan for investigation, a thorough knowledge of goals to be attained and the methods to be employed in reaching them, an unremitting zeal in adding to their knowledge by all possible means and an unstinted patriotic application of time and effort have done much to make our present status what it is. Itself without funds, the National Research Council's Committee on Aviation Medicine has guided and urged other better endowed agencies in their efforts. Specifically, the formulation of desiderata and criteria

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for testing proposed oxygen equipment is a direct and distinct contribution of the Committee.

Before beginning a detailed description of the types of oxygen equipment for military flying, it may be well to review briefly the reasons for its use. For this purpose, I have decided to show two charts which illustrate the cardinal reasons for the use of oxygen and the special requirements interposed for military aviation.

Chart I shows very graphically in parallel column the important meteorological conditions encountered in ascending to higher altitudes.

Chart II shows the total barometric pressure prevailing at increasing altitudes, the partial pressure of oxygen at normal percentage at those altitudes, the arterial saturation under these partial pressures and the arterial saturation at these altitudes when 100 per cent oxygen is breathed.

It will be noted that while breathing normal air the arterial saturation is significantly reduced even at 10,000 feet and is progressively reduced as the altitude increases. At 20,000 feet the arterial saturation is only 60 per cent. This shows why normal efficiency cannot be expected at this altitude breathing normal percentages of oxygen.

When the deficiency in partial pressure using normal percentages is made up by providing 100 per cent oxygen in a breathing apparatus, the arterial saturation continues to be adequate for physical and mental efficiency up to 30,000 feet at least. However, please note that as we approach 40,000 feet, the total barometric pressure drops so low that, even if the inspired mixture is made up of nothing but oxygen, its partial pressure is inadequate to preserve 100 per cent arterial saturation. Above these altitudes, arterial saturation can only be maintained by raising the total barometric pressure by pressurizing cabins or suits.

But replacing the deficiency of oxygen to avoid anoxia is not the complete picture. In addition to the problem of anoxia, per se, we are beset by the ogre of aeroembolism which rears its ugly head in increasing ferocity. With increasing rates of climb to higher and higher altitudes and capability of continuing at these altitudes for increasingly longer periods of time, we find that the contribution which oxygen supply apparatus can make to the solution of this problem becomes increasingly important. Without discussing aeroembolism in any detail, suffice it to say that the only practical solution we have today is the augmentation of nitrogen elimination provided by breathing pure oxygen for

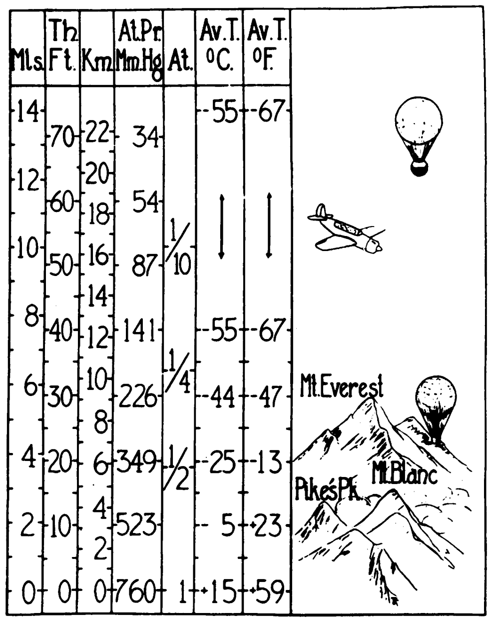

Chart I

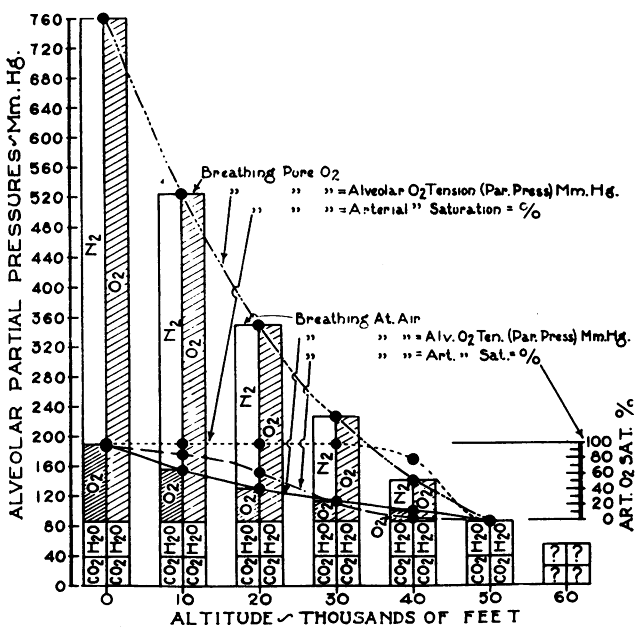

Chart II

as long as possible before attaining 30,000 feet. This means, for the purposes of this evening's discussion, that for military missions in which aeroembolism is a hazard, oxygen equipment must be capable of delivering 100 per cent oxygen from time of take off.

This brings us to the description of the types of oxygen equipment which can find application in military aviation. In the first place, it is well to reiterate that it appears undesirable to settle upon a single type of apparatus for all purposes. This is apparent by considering the wide range of variations in the need to which military aircraft are put.

On the one extreme is the very fast, rapidly climbing high altitude interception fighter. Those small planes can take their pilots to altitudes at rates which make aeroembolism an important likelihood. But their total time in the air may not exceed two hours. Oxygen must be supplied these pilots completely unadulterated from the ground up, from before take off. The nature of the mission precludes any adjustment or attention during the flight. They must be positive, simple and generously adequate. The whole flight will require but a relatively few liters of oxygen under constant flow conditions. It may be that the most practicable and reliable means of supply for this type is a constant flow system which provides a positive pressure at the face, thus reducing the necessity for close fitting masks.

At the other extreme are the long range patrol bombers with a multiple crew, never or seldom attaining to extreme altitudes yet flying for long periods at moderate oxygen altitudes. In this type, economy of oxygen is of the essence. Aeroembolism is not a problem. The crew is large enough to permit considerable frequent and delicate adjustment. Adjustment must be capable of providing for the range of activity between sedentary co-pilot and ammunition-wrestling gunners. Most of the crew may be comfortably warm. An exposed bombardier or gunner may be exposed to extremely low temperature on occasion. For this type, we may find a place for elaborate installation with facilities to adjust for wide ranges of physical exertion and altitudes, designed and operated on the basis of a cardinal need for economy.

Between these extremes there are variations in types of aircraft where oxygen installation must be judged on the basis of rate of ascent, to what altitude, for how long a flight, with what degree of exertion or cold and with what opportunity for adjustment and control of equipment. Indeed, it appears unreasonable to expect a single type of equip-

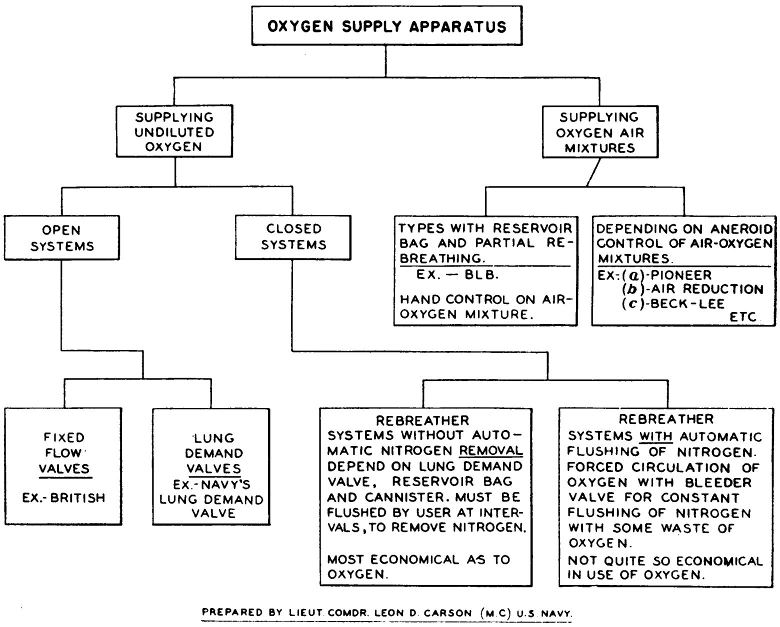

Chart III

ment to meet all requirements without some sacrifice somewhere. The analogy may be far fetched but the situation might be compared to installing the same motor in a jalopy and in a 10-ton truck. But it is equally true that there are many reasons for keeping the number of types at a minimum. Procurement, maintenance, indoctrination, familiarity, serviceability and uniformity all point to the desirability of a very limited number of types. The balance between these two concepts must be struck on a fulcrum which is ever changing as types of aircraft and tactical uses vary in relative concentration. The range of choice is apparent when we consider the types of equipment available.

Oxygen supply apparatus are divided, first, into (a) those which supply undiluted oxygen and (b) those which supply oxygen and air mixture.

Undiluted Oxygen Systems

Those supplying undiluted oxygen are divided into (1) open systems and (2) closed systems.

Open Systems

The open systems are by far the least economical of oxygen. They are the most dependable to furnish 100 per cent pure oxygen. In one case, the oxygen is supplied by fixed flow valves with no control over rates of flow. These provide a constant flow of pure oxygen through the breathing mask. They do not require expiratory leak-proof masks, have no valves to provide resistance to breathing, are not so subject to freezing as those with expiratory valves, are very reliable and are very simple in construction and operation. They are very wasteful of oxygen. In another case, operation depends upon the lung demand principle. A system of valves is incorporated to permit the flow of oxygen only during inspiration. During expiration and the pause between expiration and inspiration, the supply of oxygen is cut off. Because of this intermittent flow, this type is more economical than the fixed flow valve type but it makes no provision for the percentage of oxygen not absorbed by the lungs, more than 85 per cent oxygen being exhaled to the open air.

The lung demand type interposes a number of stipulations which require very careful control and test criteria. They must function throughout a wide range of barometric and temperature variation. They must provide adequate partial pressure of oxygen up to the physiological ceiling. They must be capable of furnishing adequate rates of flow even under extreme exertion and peaks of inspiratory demand. They depend on both inspiratory and expiratory valves which must introduce a minimum resistance and must not freeze at very low temperature and moderate wind velocities. The lung demand type requires an absolutely leak-proof mask. If there is an inspiratory leak there will be dilution by ambient air. If there are expiratory leaks, there is increased chance for frostbite and loss of economy through failure to close the lung demand valve. They must be provided with emergency by-passes. The number and exactitude of these stipulations has prompted the National Research Council's Committee on Aviation Medicine to formulate an extensive set of desiderata and test criteria. If time permitted, it would be interesting to describe these in detail.

Closed Systems

The closed systems for supplying undiluted oxygen are essentially rebreathers which provide for conservation of unabsorbed exhaled oxygen. There are two general types. In one the system is entirely closed except for a manually operated exhaust valve. Exhalation is through a cannister which absorbs oxygen and moisture (and incidentally generates a small amount of oxygen) into the breathing bag. As the rebreathing volume is depleted by absorption of oxygen in excess of that generated, the deficiency is made up by the opening of a valve from an oxygen supply system. This may be an integrally attached flask or a central low pressure supply system which may be tapped at a number of positions distributed throughout the aircraft. This is by far the most economical of all oxygen breathing apparatus. It has one significant drawback. There is no provision for automatic exhaustion of nitrogen which accumulates in the system during ascents. As the ambient barometric pressure decreases, nitrogen will appear out of solution in the cells, tissue fluids and blood into the expired air. Even though no nitrogen is introduced from the outside into the completely closed system as much as a liter may accumulate in the breathing circuit in an ascent to 18,000 feet. This accumulated nitrogen is disposed of by periodic flushing of the entire system by exhalation through the manually controlled exhaust valve. This requires conscious attention on the part of the user because there is no means of knowing the exact amount of dilution by oxygen. Also, as ascents are made to higher altitudes there will necessarily be dilution by nitrogen and this system has, therefore, a "built-in ceiling."

Another type of rebreather provides for the elimination of nitrogen by constant bleeding of a portion of the rebreathing volume. For this reason it is not so economical as the completely closed circuit type. The oxygen is forcibly circulated by an injector in the oxygen supply line. It circulates under slight positive pressure past the bleeder valve through a carbon dioxide absorbent, thus maintaining a high percentage of oxygen. Tidal air variations are provided for by a breathing bag. Preliminary tests of a model of this type gives considerable promise of its efficiency and adaptability to military flying.

Both types of rebreather have one common, very desirable feature. They supply warm oxygen. The chemical action of the carbon dioxide absorption produces considerable heat which extends into the inspired portion. At altitudes where the temperatures are low, this is a tremendously comforting thing for the user.

By the same token, they have one common serious impediment. They will not start at low temperature. No carbon dioxide absorbent will begin action in the presence of cold dry carbon dioxide alone. If the apparatus becomes chilled by not being used before cold altitudes are encountered or by climatic conditions, the exhaled moisture will condense before the exhaled oxygen and carbon dioxide reaches the absorbent. Under these circumstances the chemical reaction involved in the absorption of carbon dioxide will not begin spontaneously. This can be obviated by exhaling directly into the absorbing cannister or by artificially heating the exhaust tubing. Both of these introduce engineering and service complications. Nevertheless, the promise of economy of oxygen in the rebreather type of oxygen equipment warrants accelerated efforts to overcome this impediment.

Oxygen-Air Mixture Systems

In the interest of economy, a number of oxygen breathing apparatus have been and are being developed on the general principle of permitting dilution by air at altitudes at which 100 per cent oxygen may be unnecessary. These are mentioned in the first division in contrast to those supplying undiluted oxygen. Here, again, we find a dichotomy into those which incorporate anaeroid control of the amount of dilution by ambient air and those which depend upon varying rates of flow to provide an adequate concentration of oxygen.

Anaeroid Control Type

The anaeroid control type is essentially a lung demand type which permits decreasing dilution of ambient air up to a minimum altitude above which only 100 per cent oxygen is acceptable. For the kinds of flying to which this type is adapted, it need not supply oxygen under 8,000 feet but must supply pure oxygen at 25,000 feet and over. Within this range the increments of oxygen and air may vary, being governed on the one hand by a minimum partial pressure of oxygen of 70 mm. mercury and on the other hand by economy of oxygen.

Several models of this type of equipment are being developed and tested. They vary in certain details such as anaeroid control of the oxygen supply, the air supply or both; methods of mixing; reduction of pressure from high or low pressure supply lines; means of providing for peak inhalations, etc., but, essentially, they embody the same general principles. To find wide or general applications, they must be provided with means to shut off the dilution and supply pure oxygen at all barometric pressures.

Rate of Flow Control Type

Any type of diluter supply system which depends upon varying rates of flow of oxygen to a breathing bag to provide for adequate concentration of oxygen at varying altitudes and exertion and does not incorporate either manual or automatic means for controlling the amount of air intake, has certain basic fallacies. If the rate of flow is adequate to provide for high altitudes and moderate exertion, it becomes essentially a free flow apparatus and economy is lost. If the amount of air dilution is unknown or unpredictable it will expose the user to the insidious influence of anoxia which may become poignant at any time as a sudden and catastrophic collapse.

This discussion is purposely avoiding inclusion of the different means of supplying oxygen to the aircraft, whether liquid or gaseous, high or low pressure flasks or hypothetically possible means of generation or compressing in the aircraft. These are essentially engineering problems. Two cardinal requirements must be observed: the oxygen must be pure and it must be dry. A detailed discussion of oxygen masks and helmets has also been scrupulously avoided. This subject is too interesting and intriguing to be sketchily included in this paper which has already consumed too much time.

Types Being Used

Just a word about the types being used by air services today. From information which reaches us through liaison channels, it may be said that, in general, European combatants are using models of the following types of equipment: The R.A.F. is using a type of free flow apparatus which can be adjusted for different altitudes and does not require a leak-proof sealed mask. They are making rapid progress in the development and extension to service of more economical equipment, better fitting masks and means for providing oxygen. The Luftwaffe has profited by their years of peace-time preparation and has the best equipment in service use today. They have concentrated on a lung demand type which is characteristically well designed and built, is very efficient and foolproof, has been perfected by years of meticulous research and extreme service proving and could be profitably copied by any air service. In our service we are well equipped with oxygen apparatus. The Navy uses a lung demand type and the Navy rebreather. They are quite satisfactory. The Army Air Forces are using a rate of flow regulator which is meeting service needs.

We have had an excellent year of accelerated research, development and testing of improved oxygen equipment. In a subject as important as oxygen supply apparatus for military aviation, there should be no let-up in this program of improvement.

Tremendous strides have been made, thanks to the characteristically American kind of all out service of brains, sweat, ingenuity and productivity. We are prepared to write the detailed specifications for the immediate mass production of the best types of oxygen equipment to meet the needs of our growing flying services. Those who have contributed to this development and have made our confidence justifiable, have every reason to be genuinely proud.